Predictive Regulation: Allostasis, Behavioural Flexibility and Fear Learning

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Abstract. Dynamical systems perspectives on emotion emphasize the importance of the regulatory interplay between brain, body and environment to adaptive behaviour. We suggest that a key facet of emotions, above all fear, consistent with this perspective lies in the allostatic regulation of constitutive/behavioural dynamics in terms of prediction and behavioural biases linking internal needs to external adaptive concerns. Allostatic emotional regulation in organizationally complex organisms permits enhanced adaptive behavioural flexibility relative to more reactive homeostatic dynamical systems. We discuss emotions as regulatory phenomena and provide a brief description of work in progress that will facilitate the gleaning of insights in this regard.

Keywords: Emotion, Allostasis, Homeostasis, Metaparameters, Allostat

1 Behavioural Flexibility and Emotion

Approaches to the study of adaptive behaviour that are not just biologically inspired but bio-organizationally inspired ([1]) have been gaining momentum in recent years within a perspective that highlights the importance of agent embodiment – the study of the relation of brain, body and environment (see [2]). A key aspect of adaptive behaviour is flexibility. Di Paolo and Iizuka [3] identify a feature of such flexibility in the cycling between behavioural “openness” and “ongoing coping”. They suggest that in AI and robotics analysis of situated action has focused on ‘ongoing coping’: robustness to distractors, based on well-developed sensorimotor skills. Less emphasis has been placed when such ongoing coping breaks down. They suggest that in an (alternative) “open state with undefined goals, an agent may be drawn by environmental or internal events into forming a novel intention and retroactively investing such a ‘distracting’ event with meaning” (p.418). While ongoing coping is pertinent to producing ‘here and now’ behaviour based on an existing repertoire, openness permits extension of the repertoire through learning sensorimotor contingencies not necessarily of immediate benefit to the organism. Agents able to make use of these two modes of behaving in the world have regulatory dynamics that are less constrained by design decisions – including use and choice of 'value systems'. Terminology that parallels this openness/ongoing coping dichotomy includes 'opportunism' vs 'persistence' (e.g. [4]) and 'exploration' vs 'exploitation' (e.g. [8]). What all these pairs of behavioural polarities have in common is that they are coherently manifested through cyclic transitions between states (attractors) arrived at through the regulatory activity of *emotions*.

Emotions proper [5] can be thought of as drivers ('e-moters') of behavioural transitions subsequent to emergent constitutive organization [6] applicable to whole-organism dynamics as it is perturbed by sensorimotor feedback: they are rooted in nested *homeostatic* processes starting at the most basic level of organismic constitution, i.e. metabolism; in encephalized organisms, that have the capacity for meta-level constitutive regulation based on emotional feelings, they also involve mechanisms that coordinate patterns of metabolic and nervous system activity requisite to adaptive responding.

Neuromodulators provide mechanisms through which such whole-organism dynamics can be regulated and are viewed by many as emotion constituents [5],[7]. Doya [8] suggests neuromodulators serve as regulatory *metaparameters* that modulate, for example, learning rate, time scale of evaluation but also degree and likelihood of exploration vs exploitation (via dopamine and noradrenaline). Through these neurohormones behaviour and apportioning of internal resources are coordinated enabling a coherent transition from one whole-organism state to another.

2 Predictive Regulation: Fear and Allostasis

Where homeostatic regulation of local systems emphasizes reactive responding and negative feedback – a 'drive' to bring the local system back within homeostatic bounds – emotional regulation of constitutive and behavioural organization can involve anticipation and positive feedback. The term *allostasis* ([9],[10],[11]) encapsulates such emotional regulation and the paradigmatic allostatic system is considered amygdala-centred [10],[11] whereby neurophysiological regulation as governed by, above all, its connections to hypothalamus and prefrontal cortex generates fear responding that, transiently (or more persistently in the case of pathophysiological ‘allostatic load’) recruits metabolic resources and organizes nervous system activity according to a positive feedback dynamic. Such positive feedback permits a transiently stable attractor state, ultimately offset by negative feedback, e.g. in the hypothalamus, which enables emotional learning in organisms with complex constitutive organizations [7] (also see [12] for critique). Through linking the fundamental organismic need for internal stability to the requirement to adapt in a complex, changing and unpredictable world emotional dynamics, particularly fear, embody the allostatic notion of “stability through change” ([10]). This “change” manifests itself in a sort of predictive regulation [10] which recruits metabolic resources according to prioritized sub-systems whose input sensitivity is modulated in accordance with anticipated bodily requirements. This affords appropriate behavioural activity albeit to the short-term detriment of reactive homeostatic stability; instead, a more long-term, ontogenetic global dynamic is achieved serving complex constitutive organization in an unpredictable and challenging environment.

3 Fear Learning and Regulation: An Amygdala-centric Model

Our work presently concerns developing an amygdala-centric model (see [13],[14] for recent work), tested at different levels of abstraction, that provides neural and bodily activity that isn’t merely reactive according to a pre-defined homeostatic ideal state but through predictive regulation allows for a higher order of adaptive behaviour over extended time periods – it may be considered a bio-organizationally inspired *allostat* (also see [15]). The model is based on a conception of emotional learning as emergent from more than just reactive homeostatic control. The systematic testing, extension, and integration of two models of emotional learning (see [16],[17]) provides a mechanism for regulation of *metaparameters*. This is achieved through modelling the interplay between amygdala and prefrontal cortex (specifically orbitofrontal cortex) providing: 1) attentional salience to emotionally reinforced stimuli, 2) expectations of outcomes based on internal needs and ongoing goals ([18]). The former mechanism 1) permits response priming for behavioural transition, while 2) allows for risk assessment with the potential for response inhibition (see [19]). Transient stability of brain-body/behavioural and environmental states then allows for emotional (in this case fear) learning. Such an integrated model is hypothesized to enable agents to exhibit enhanced adaptivity ([20]), as compared to merely reactively homeostatically regulated controls, according to internal and external demands. This can occur as a consequence of appropriate cycling and transitioning between behaviours across a number of challenging tasks relevant to risk assessment and reward/punishment prediction.

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